



Integrated Design Center / Mission Design Laboratory

PACE 2012 Mission

Flight Software

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N A S A G O D D A R D S P A C E F L I G H T C E N T E R



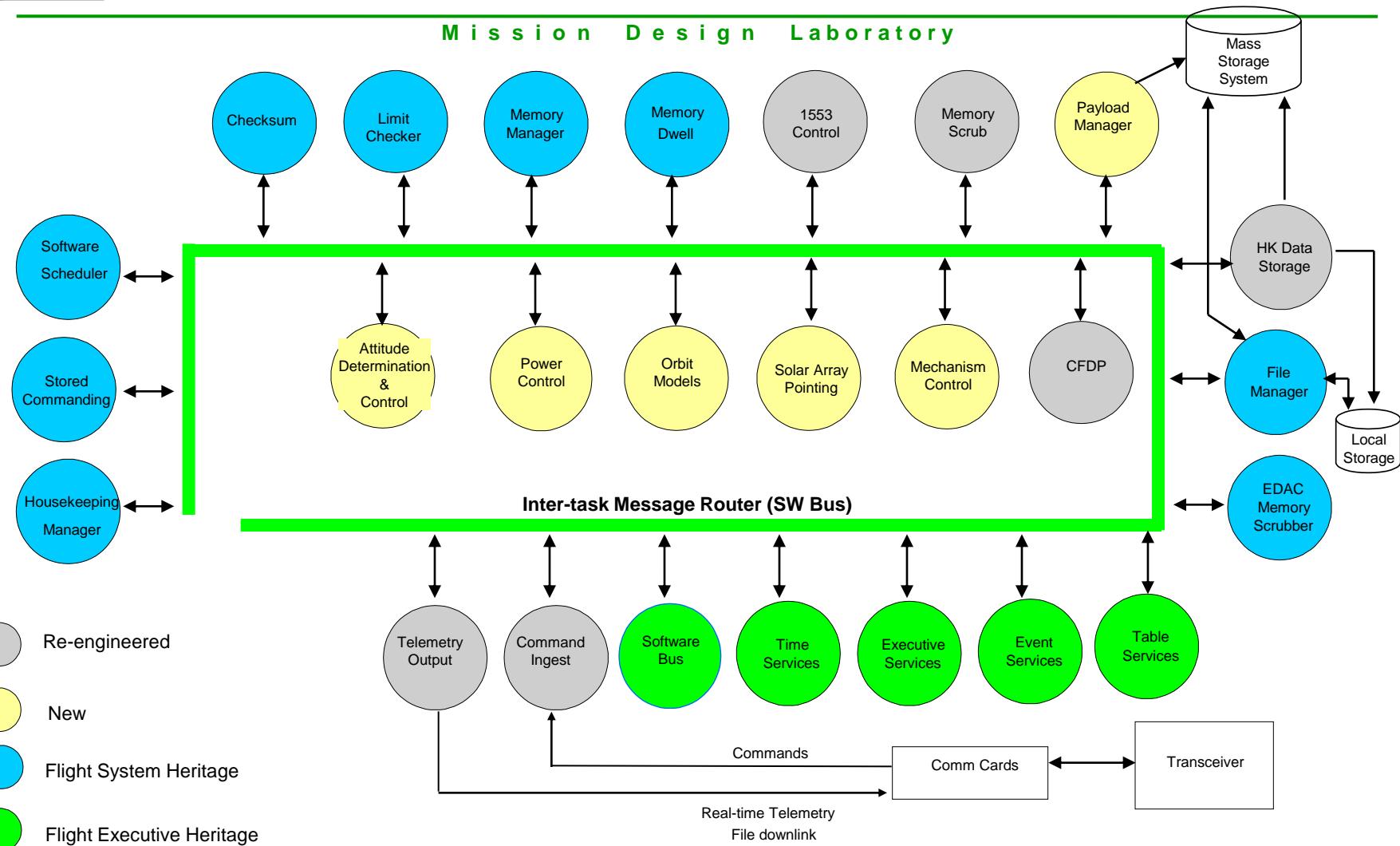
Overview

M I S S I O N D E S I G N L A B O R A T O R Y

- **Spacecraft flight software for a non redundant system**
 - Command and data handling
 - 3-axis attitude control system
 - Payload support including heath & safety monitoring
 - Switched Services Management
 - Solar Array deployment and pointing control
- **Development approach consistent with NPR 7150.2. Reuse of some existing flight software**
- **Three testbeds for flight sw/hw I/Fs, FSW build/system tests**
- **Flight software sustaining engineering**
- ***Flight hardware/software based on proven system, no creditable technical risk identified (i.e., no show-stoppers)***



Flight SW Architecture



FSW development will use ASIST T&C GSE (to maximize reuse of heritage FSW test product)



Assumptions

M I S S I O N D E S I G N L A B O R A T O R Y

- Class C non-redundant avionics
- Broad-Reach Engineering BRE440 C&DH avionics
- Diagnostic S/W and SUROM will be COTS from Broad-Reach
- Payload will perform compression of science data
- Payload will packetize all science and housekeeping data in CCSDS telemetry packets and timestamp all packets
- Passive thermal control
- GNC FSW development will use modeling and autocode generation method
- Safe-hold (Sun avoidance for payload, power positive & thermally safe) will be manually developed by an independent team
- Controlled Re-entry
- FSW development will use ASIST T&C GSE (to maximize reuse of heritage FSW test product)





FSW Requirements (1 of 3)

M I S S I O N D E S I G N L A B O R A T O R Y

- FSW Product Development Process Shall Comply with NPR 7150.2A, NASA-STD-8719.13B. Class B for all mission critical FSW
- Uplink/downlink management including Communication Security management. FSW shall be capable of supporting the following COMM rates:
 - S-band 2 kbps command, 8 kbps HK telemetry
 - X-band 105 Mbps science data, payload telemetry, and S/C telemetry
 - TDRSS 1 kbps command, 5 kbps telemetry
- Command and data handling, comply with CCSDS
- Time management and distribution, 1.0 millisecond accuracy with periodic updates from ground
- 3-axis stabilized attitude control system
 - CSS(8), Earth Sensor (3), Magnetometers(2), Star Tracker (2), Gyro (1),
 - Reaction Wheels(4, RW), Magnetic Torquer Bars(3), Thrusters(4)
 - Up to 10 Hz sensors data acquisition and processing; 10 Hz control cycle
 - Up to 10 Hz Kalman filter
 - ACS control modes: Sun Acquisition; Earth Acquisition, Science , Lunar Calibration, Orbit Adjustment, De-orbit (decommission)
 - Ground initiated momentum management using thrusters (i.e. delta H)
- 2 Hz Safe-hold Controller software using CSS, Mag, Gyro, Earth Sensor, RW
- Onboard ephemeris propagator with periodic ground updates



FSW Requirements (2 of 3)

M I S S I O N D E S I G N L A B O R A T O R Y

- **Payload support**

- Provide time synch, 1.0 millisecond accuracy
- SpaceWire Bus for science data collection
- 1553 Bus for payload command and housekeeping telemetry communications
- Payload commands pass through
- C&DH will filter science data to accommodate latitude concerns regarding science collection
 - DESIGN TRADE later: filter science data based upon time vs operator controlled collection periods
- Health and Safety monitoring

- **Mechanisms Control**

- Solar Array deployment
- Solar Array drive controller

- **Recorder Memory Management, store and forward HK and science data using CCSDS File Delivery Protocol (cFDP)**

- 91.4 Gbits for 2 orbits (3.3 hours), volume includes 30% margin

- **S/C Power System Electronic Support**

- Switched Services





FSW Requirements (3 of 3)

M i s s i o n D e s i g n L a b o r a t o r y

- **Onboard autonomy**
 - Absolute & relative time-tagged command sequences
 - Limit checker
- **Health & Safety Management**
 - Memory Checksum Management
 - EDAC Memory Scrub Management
 - Parameter Table & Memory Management
- **Serviceable: allow FSW updates, patches and/or entire module (capabilities to start, stop, delete module without shutting down the system)**
- **Provides three spacecraft simulators – one for each payload development teams and one spare**





Processor Utilization Estimates

M i s s i o n D e s i g n L a b o r a t o r y

Component	CPU Percentages		BAE750(%) Base Value
	25 Mhz	16 Mhz	
cFE	0.12	0.19	0.05
Housekeeping Data Acq	0.12	0.19	0.05
Health and Safety	0.24	0.38	0.10
Memory Manager	0.01	0.02	0.01
Memory Dwell	0.17	0.26	0.07
Stored Commands	0.11	0.17	0.04
Limit Checker	0.10	0.15	0.04
Scheduler	1.46	2.29	0.61
1553 Bus Control	6.96	10.88	2.90
Command Ingest	0.01	0.02	0.01
R/T Telemetry Output	2.28	3.56	0.95
File Manager	0.02	0.04	0.01
Instrument Manager	2.40	3.75	1.00
Data Storage	4.80	7.50	2.00
Memory Scrub	2.40	3.75	1.00
Checksum	0.48	0.75	0.20
CFDP	36.00	56.25	15.00
SpaceWire Control	12.00	18.75	5.00
Power Control	0.48	0.75	0.20
Solar Array Pointing	1.20	1.88	0.50
Attitude Control	96.00	150.00	10.00
ACS Orbit Models	9.60	15.00	1.00
Subtotal	176.96	276.50	40.73

~59% margin





Source Line of Code (SLOC) Estimates

M i s s i o n D e s i g n L a b o r a t o r y

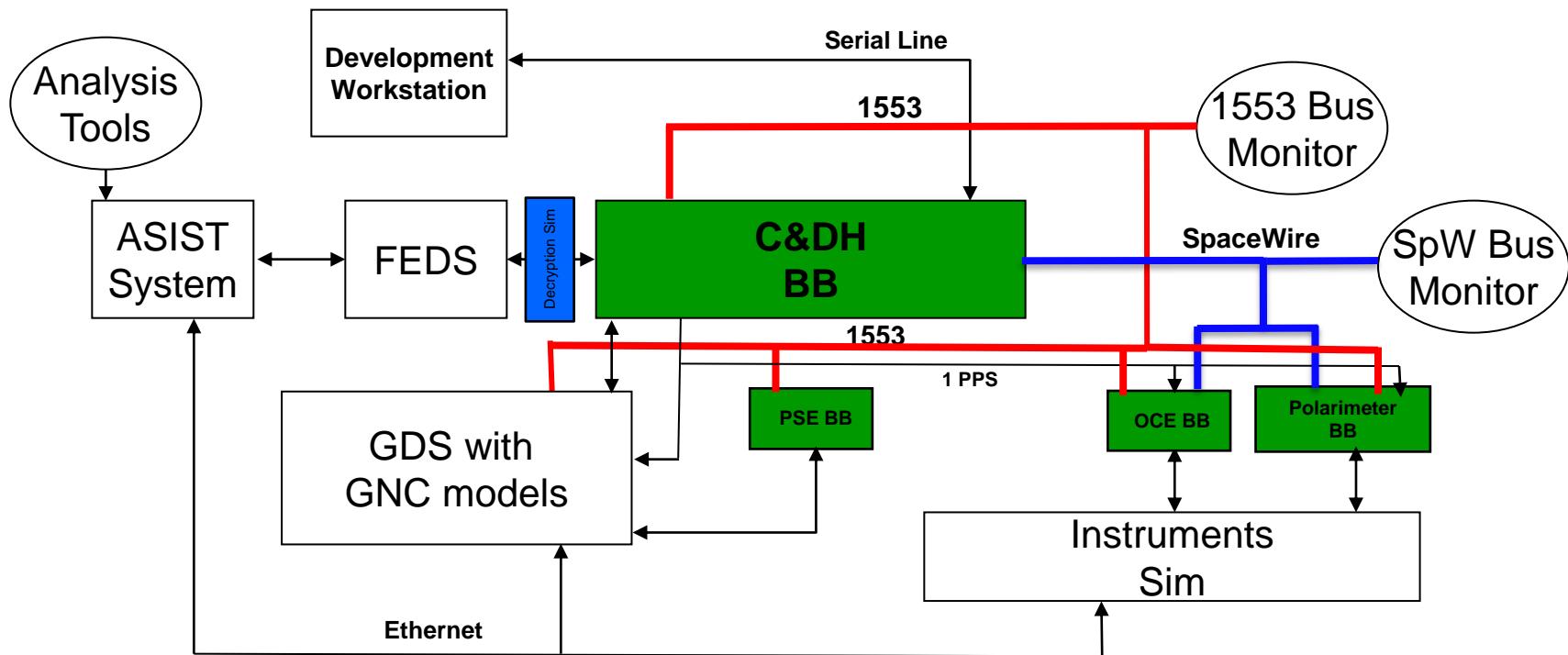
Module Name (Hierarchical/Indented list as appropriate)	Environment (Flight, Ground)	SW type (Control, Data mining, Database, Web, etc.)	(New, Reuse, Rehost, Maintenance, COTS I&T, etc.)	Development Method	Software Lines of Code (Logical))					% Retest needed on Reuse	
					Total	New	Reuse		Deleted		
							Total Reuse SLOC	% Re-engin.			
OS API & OSAL	Flight	OS/Executive	COTS I&T	OTS integration	2338	0	2338	0%	0	10	
Boot Loader	Flight	Flight System	Modification, Minor	Waterfall	1868	100	1768	10%	0	100	
BSP	Flight	Flight System	Reengineering, Major	Spiral	1492	1000	492	80%	0	100	
Executive Services	Flight	OS/Executive	Integrate /w config	OTS integration	4737	0	4737	0%	0	10	
Event Service	Flight	Flight System	Integrate /w config	OTS integration	1429	0	1429	0%	0	10	
File System	Flight	Flight System	Integrate /w config	OTS integration	763	0	763	0%	0	10	
Mission Config Include Files	Flight	Flight System	Integrate /w config	OTS integration	1857	1857	0	100%	0	100	
Software Bus	Flight	Flight System	Integrate /w config	OTS integration	2017	0	2017	0%	0	10	
Table Service	Flight	Flight System	Integrate /w config	OTS integration	2182	0	2182	0%	0	10	
Time Service	Flight	Flight System	Integrate /w config	OTS integration	1941	0	1941	0%	0	10	
cFE Configuration (hdr files)	Flight	Flight System	Integrate /w config	OTS integration	226	0	226	0%	0	10	
cFE platform Support Pkg	Flight	Flight System	New	Waterfall	827	400	427	50%	0	100	
CFS Library	Flight	Flight System	Integrate /w config	OTS integration	166	0	166	0%	0	10	
Checksum	Flight	Flight System	Integrate /w config	OTS integration	2811	0	2811	0%	0	10	
File Manager	Flight	Flight System	Integrate /w config	OTS integration	1664	0	1664	0%	0	10	
File Commanding	Flight	Flight System	Integrate /w config	OTS integration	447	0	447	0%	0	10	
Health & Safety	Flight	Flight System	Integrate /w config	OTS integration	1433	0	1433	0%	0	10	
Memory Manager	Flight	Flight System	Integrate /w config	OTS integration	1927	0	1927	0%	0	10	
Scheduler	Flight	Flight System	Integrate /w config	OTS integration	1067	0	1067	0%	0	10	
Housekeeping	Flight	Flight System	Modification, Major	Waterfall	554	300	254	0%	0	100	
Memory Dwell	Flight	Flight System	Integrate /w config	OTS integration	1003	0	1003	0%	0	10	
Memory Scrub (EDAC)	Flight	Flight System	Modification, average	Waterfall	1538	300	1238	10%	0	100	
Stored Commands	Flight	Flight System	Integrate /w config	OTS integration	2033	0	2033	0%	0	10	
Limit Checker	Flight	Flight System	Integrate /w config	OTS integration	1812	0	1812	0%	0	10	
Data Storage	Flight	Flight System	Integrate /w config	OTS integration	1691	0	1691	0%	0	10	
Command Ingest	Flight	Flight System	Modification, average	Waterfall	1721	300	1421	20%	0	100	
Telemetry Output	Flight	Flight System	Modification, Minor	Waterfall	3067	500	2567	20%	0	100	
cFDP	Flight	Flight System	Modification, Minor	Waterfall	8286	1000	7286	20%	0	100	
Time Manager	Flight	Flight System	Modification, Minor	Waterfall	1045	100	945	20%	0	100	
Recorder Manager	Flight	Flight System	Modification, Minor	Waterfall	1155	250	905	20%	0	100	
Housekeeping Recorder	Flight	Flight System	Modification, Minor	Waterfall	590	295	295	50%	0	100	
1553 Bus Control	Flight	Flight System	Modification, Major	Spiral	3947	1500	2447	50%	0	100	
SpaceWire Bus Control	Flight	Flight System	Modification, Major	Spiral	2676	1000	1676	50%	0	100	
C&DH Library	Flight	Flight System	Integrate /w config	OTS integration	4267	0	4267	0%	0	10	
Math Library	Flight	Flight System	Integrate /w config	OTS integration	1123	0	1123	0%	0	10	
GNC Application Framework	Flight	Flight System	Integrate /w config	OTS integration	1041	0	1041	0%	0	10	
ACS Models & Ephemerides	Flight	Flight System	Integrate /w config	OTS integration	2489	0	2489	0%	0	10	
ACS Sensor Data Acquisition	Flight	Flight System	Modification, Major	Waterfall	3561	1000	2561	100%	0	100	
ACS Sensor Data Processing	Flight	Flight System	Modification, Major	Waterfall	3973	1000	2973	100%	0	100	
ACS Actuator Cmd Processing	Flight	Flight System	Modification, Major	Waterfall	5614	1500	4114	100%	0	100	
ACS Control Laws	Flight	Flight System	New	Waterfall	6123	5716	407	100%	0	100	
Solar Array Pointing Control	Flight	Flight System	New	Waterfall	1000	1000	0	100%	0	100	
Power Control	Flight	Flight System	New	Waterfall	2008	2008	0	100%	0	100	
FSW Tables (ex: SC & filter Tables)	Flight	Flight System	New	Waterfall	6500	6500	0	100%	0	100	
Payload Manager	Flight	Flight System	New	Waterfall	2238	2238	0	100%	0	100	
Total SLOC					102247	29864	72383				
								71%	Reuse		





C&DH/PSE FSW Testbed

M i s s i o n D e s i g n L a b o r a t o r y



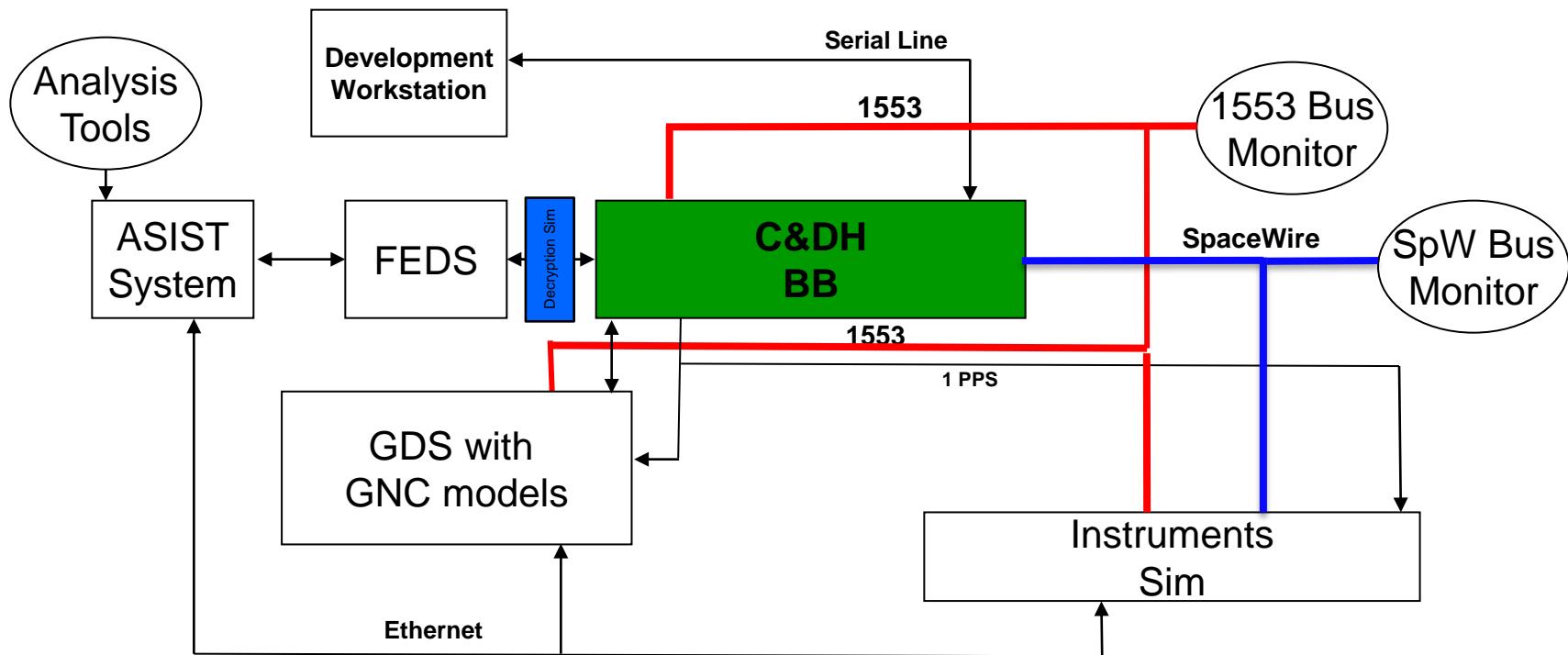
- **Top-Level Requirements:**
 - Support C&DH FSW development
 - Support C&DH FSW build integration
 - Support C&DH FSW build test
 - GDS to checkout GNC I/Fs

FSW development will use ASIST T&C GSE (to maximize reuse of heritage FSW test product)



ACS FSW Testbed

M i s s i o n D e s i g n L a b o r a t o r y

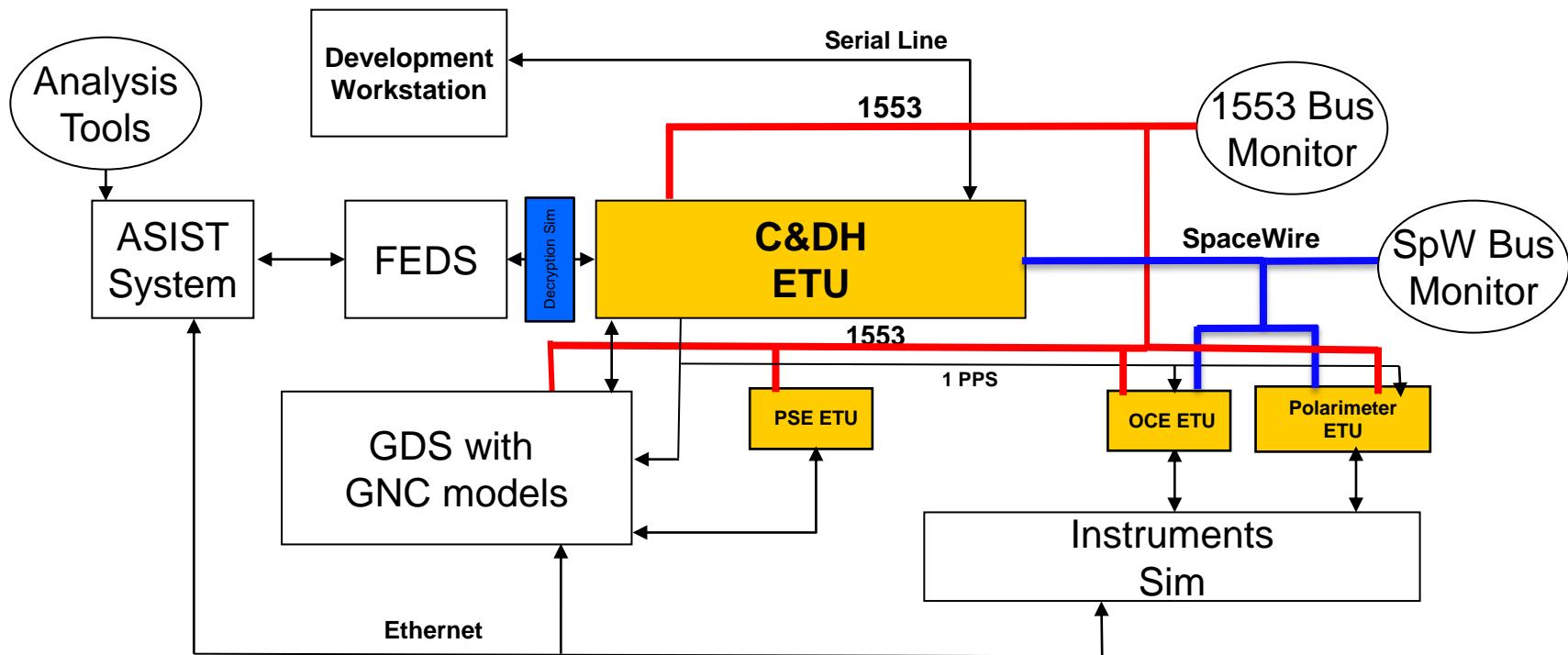


- **Top-Level Requirements:**
 - **Support GNC FSW development**
 - **Support GNC FSW build integration**
 - **Support GNC FSW build test**

FSW development will use ASIST T&C GSE (to maximize reuse of heritage FSW test product)

FSW System/Maintenance Testbed

M i s s i o n D e s i g n L a b o r a t o r y



- Top-Level Requirements:**
 - Support FSW system test
 - Support mission operation training
 - Support FSW maintenance

FSW development will use ASIST T&C GSE (to maximize reuse of heritage FSW test product)



Elements Required For FSW Development (Inc. Deliverables/Receivables)

M I S S I O N D E S I G N L A B O R A T O R Y

PROVIDER	ITEM
Flight	<ul style="list-style-type: none">• S/C Simulator (3)• Flight Software Builds
Ground System	<ul style="list-style-type: none">• ASIST GSE (3)• Front-End Simulator (3)
C&DH	<ul style="list-style-type: none">• C&DH BB (2)• C&DH ETU set (1)
ACS	<ul style="list-style-type: none">• ACS Dynamic Simulator (3)
Power	<ul style="list-style-type: none">• PSE BB (1)• PSE ETU (1)
Instrument Developers	<ul style="list-style-type: none">• OCE BB and Polarimeter BB set (1)• OCE ETU and Polarimeter ETU set (1)• Instruments Simulator (3)





Future Work

M I S S I O N D E S I G N L A B O R A T O R Y

- **Broadcast Mode for Science Data will require more analysis**

- Requirements/Constraints GIVEN:
 - Realtime OCE and Polarimeter science data downlinked @ 12.2 Mbps (plus overhead)
 - Science data will be recorded when performing realtime downlink (broadcast mode)
- 12.2 Mbps science data downlink in realtime is unlikely to be cFDP protocol
- More likely broadcast science data will be telemetered as AOS frames





Acronym list

M i s s i o n D e s i g n L a b o r a t o r y

• ACS	Attitude Control System	• HGA	High Gain Antenna
• ASIST	Advanced Spacecraft Integration and Test System	• HK	Housekeeping
• BB	Breadboard	• Mbps	Megabit per second
• C&DH	Command and Data Handling	• MW	Momentum Wheel
• CADU	Channel Access Data Unit	• PDU	Playback Data Unit (cFDP)
• CCSDS	Consultative Committee for Space Data Standards	• ROM	Read-Only Memory
• cFDP	CCSDS File Delivery Protocol	• RW	Reaction Wheel
• cFE	Core Flight (S/W) Executive	• RWA	Reaction Wheel Assembly
• CFS	Core Flight (S/W) System	• SA	Solar Array
• COTS	Commercial Off the Shelf	• SIRU	Space Inertial Reference unit
• CSS	Coarse Sun Sensor	• SpW	SpaceWire
• DSS	Digital Sun Sensor	• SSR	Solid State Recorder
• EDAC	Error Detection and Correction (circuitry)	• ST	Star Tracker
• ETU	Engineering Test Unit	• SUROM	Start-up ROM (boot program)
• FSW	Flight Software	• T&C	Telemetry and Command
• FSS	Fine Sun Sensor	• VCDU	Virtual Channel Data Unit
• GNC	Guidance, Navigation and Control		
• GDS	GSFC Dynamics Simulator		
• GSE	Ground Support (test) Equipment		





Backup Slides

M i s s i o n D e s i g n L a b o r a t o r y

- System Diagrams from Avionics





Electrical System Diagram (from Avionics team)

